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of G. Derby

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ANTHRACITE

AND

HEALTH.

BY

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AN INQUIRY

INTO THE

INFLUENCE UPON HEALTH

OF

ANTHRACITE COAL

WHEN USED AS FUEL FOR WARMING DWELLING-HOUSES,

WITH SOME REMARKS UPON SPECIAL EVAPORATING APPARATUS.

BY

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PREFACE.

The following observations upon the influence of anthracite fuel upon health were read before the "Boston Society for Medical Improvement," at their meeting on the 10th instant.

The paper is published in this form in the hope that it may contribute to a general knowledge of one of the many ways in which disease may be prevented and health may be preserved.

102 Charles Street, Boston,
February 20, 1868.

ANTHRACITE AND HEALTH.

Sixty years ago anthracite coal was regarded all over the world as incombustible refuse. Its use in America dates from the period when supplies of English coal for the manufacturers of the Middle States were cut off by the war of 1812. Attention was then drawn to the anthracite deposits in Pennsylvania, and many vain attempts were made to use them.

These efforts were finally successful; and within ten years, or about 1820, the use of hard coal for manufacturing purposes became general. It was not however until about 1830 that it began to be employed for warming houses, and still later for cooking. Recently it has become the fuel generally used for both these purposes.

There has always however been a minority of persons who have disliked it in their houses, who have resisted its introduction in the rooms in which they lived; and not a few who after trial have discarded it and substituted bituminous coal and wood.

Its great economy of labor and its heating power have been sufficient recommendations however to allow of its almost universal use in hot-air furnaces; and at the present time it is safe to say that ninety-nine dwelling-houses out of a hundred in Boston are, in whole or in part, warmed by this fuel burned in iron stoves, or in the iron fire-pot of a furnace which is but a stove in another form.

The object of this inquiry is to learn if we can whether this is conducive to health; and if injurious why it is so.

It is a matter of common observation that different kinds of fuel give apparently different kinds of heat. Hard coal on the one hand, and soft coal and wood on the other, produce different impressions. Anthracite burning in an open grate affects, if not everybody, certainly a great majority of persons very differently from an open fire of wood.

The heat is radiant in both cases, warming the floor and the furniture and the bodies both animate and inanimate on which its rays fall; the temperature may be the same; the ventilation also is, or may be, perfectly good in both cases; yet the impressions, not the moral impressions affected by a beautiful fire or pleasant associations, but the impressions upon the nervous system are quite different.

With a certain proportion of persons who may

be supposed to be more sensitive, anthracite burned in this way under the most apparently favorable circumstances causes difficult respiration, headache (often described as if an iron hoop were bound round the head), dizziness, confusion of ideas, languor, heaviness, — a group of symptoms leading to the suspicion of the presence of a narcotic poison. These unpleasant sensations are generally removed almost immediately on breathing the open air.

Many other persons without analyzing the effects it produces do not like a hard-coal fire, and in spite of its convenience and economy will not use it in the rooms which they occupy through the day, and burn soft coal or wood in their parlors and business-offices at twice the cost of anthracite.

The same difference may be observed in stoves burning wood or anthracite, although it is less apparent because usually in both cases ventilation is bad, and impressions produced by foul air obscure those which proceed from fuel.

In the case of furnaces we have a fair subject of comparison between those which pass the air over and around a heated fire-pot containing anthracite, and those in which the air is conducted through coils of pipe containing either steam or hot water, and enclosed in a confined space in the cellar or basement.

In each of these cases the air is forced into the rooms above, and ventilation may be perfectly

good; the temperature may be the same; yet the impressions made by these two kinds of heated air, one proceeding from a fire-pot filled with anthracite, the other from pipes filled with steam condensing into water, or with hot water, are to many persons quite different and can be distinguished.

If further proof is needed of the reality of this difference it may be found in the action of these two kinds of heating-apparatus upon plants.

It is notoriously difficult to make the more delicate varieties flourish in houses warmed by anthracite stoves or furnaces. A gentleman conversant with plants informs the writer that experience has proved that hot-air anthracite furnaces, like those in dwelling-houses, cannot be used in greenhouses.

Where anthracite is the fuel employed, as it generally is, the fire is in a separate building and heat is communicated to the greenhouse either by hot-water pipes carried round its walls and under its floor, or by brick flues carrying the heated air with the products of combustion by a long and circuitous passage round the building; heat being thus radiated either from the water-pipes or the brick-work.

In seeking an explanation of these phenomena, it is proper to mention certain conjectures which have been made as to the physiological effects of heat proceeding from different sources. The anal-

ogy with light is the basis upon which they rest. Thus it has been suggested that rays of heat from different bodies may have properties corresponding with their refrangibility and rates of vibration. As impressions of color are found to depend on rates of undulation in rays of light, so the various impressions of heat upon the human body may depend upon the rates of undulation in rays of heat.

The belief is very generally entertained among those who feel and complain of the unpleasant effects of anthracite fires that they are due to dryness of the air. It is also not uncommonly believed that passing air over red-hot iron removes its oxygen as well as its moisture; deprives it, in some way, of qualities essential to the support of respiration, and burns the dust which it contains; that all these things are injurious to health; and that the remedies are found in moderately heated iron and abundant evaporation. We propose, as briefly as possible, to consider these several statements.

Iron excessively heated may finally be burned, and by that process deprive the air in contact with it of a portion of its oxygen. In no other way can its oxygen be removed, and how slow this process is may be known by the number of years required to burn the fire-pot of a furnace, the chief destruction of course going on within and not without.

It is within bounds to say that one pair of lungs will consume more oxygen in a given time than the heated iron of a hundred furnaces. In so far as oxygen and nitrogen are concerned, a furnace, however heated, has no power to change these gases in the slightest degree except by burning and consuming the iron in their passage over it. Excessively heated iron burns the dust with which in crowded towns the air is always filled. A stream of sunlight falling in a darkened room will show how abundant this is. It consists of the detritus of every imaginable thing used in our social economy; clothing, food, organic emanations from our bodies and those of the lower animals, shoe-leather, mineral particles raised from the earth, besides the germs of infusorial life concerned in all the processes of putrefaction and decay.

It seems at least probable that the destruction of most of these substances would relieve us from danger, as they are supposed to be agents in the propagation of disease. The part which infusorial life may play in the human economy is obscure; any useful office which it fulfils in the living body is as yet unproved. So far as known its duties are exclusively with dead organic matter. It has been suggested that the particles of which dust is composed are not burned in their passage over heated iron, but that organic material may be so changed

by heat as to give it new properties, the nature of which is unknown, but which may have an injurious influence. It is quite possible this may be so, but it is unproved. We know that dust so charred has an offensive odor.

Has iron excessively heated any power of abstracting moisture from air passing over it, or any influence upon the vapor of the air differing from that which it receives from iron heated to a moderate degree? The drying of air by heating it is relative and not absolute. The capacity of air to hold water in the form of invisible vapor is enormously increased as its temperature is raised. Thus air at 10° above zero, Fahrenheit, will retain 1.11 grains, at 30° 2.21 grains, at 50° 4.28 grains, and at 70° 8 grains to the cubic foot. These are the points of saturation, and any addition of vapor at these temperatures must fall as visible water. Instead of abstracting moisture, heated substances of any sort however heated and to whatever degree simply increase the avidity of air subjected to their influence for the absorption and retention of additional amounts. Theoretically it makes no difference in so far as moisture is concerned whether the air of a room at 65° or 70° has attained this temperature by passing over a long range of pipes containing water at a temperature of 160°, steam at a temperature where it is condensed into water (212°), or red-hot iron plates at a temperature of 1,000° to 1,500°. Practically, we are prepared to

show that this is confirmed by observation. Seven dry and wet-bulb hygrometers made by Mr. Siefert and carefully compared before being issued, were placed on the 27th January, 1868, in as many different buildings warmed in all the principal modes now in use, viz., hot-water pipes, steam pipes, furnaces for burning anthracite, one furnace for burning wood, and one large room warmed by an open grate burning anthracite.

The object of the inquiry being to ascertain whether the kind of heating apparatus had any influence upon the moisture of the air, and particularly whether iron heated to 1,000° made the air passing over it dryer than iron heated to 160°, no evaporating apparatus was used in any of the seven buildings except the fifth.

These observations were made in the coldest season of the year, and when all the means of warming houses which our climate can demand were required. During the first thirteen days the mercury never rose above 32° and was once observed below zero.

The markings of the dry and wet bulbs were noted at 9 A. M. and 2 P. M., and from them the relative humidity was ascertained by reference to Glaisher's Psychrometrical Tables published in the collections of the Smithsonian Institution.

No. 1. A moderate-sized private dwelling-house, warmed entirely by a hot-air furnace burning anthracite. Fire-pot not lined; coal in contact with iron. No evaporating apparatus.

No. 2. A larger private dwelling-house, warmed by a hot-air furnace burning anthracite. No evaporating apparatus.

No. 3. The library of the State House, warmed by hot-water pipes in the cellar until February 5th; on and after that date by steam pipes in the cellar and a few coils in the room. No evaporating apparatus.

No. 4. Library of the Boston Athenæum, warmed by hot-water pipes in the cellar. No evaporating apparatus.

No. 5. A large room (about twenty-two feet square) on first story of a dwelling-house, warmed by a grate burning anthracite. The entry of this house moderately warmed by an anthracite furnace over which from six to eight quarts of water are evaporated daily. No register from furnace enters the room where observations were made.

No. 6. A dwelling-house, warmed by steam pipes enclosed in basement. No evaporating apparatus.

No. 7. A dwelling-house, warmed by a furnace burning only wood. No evaporating apparatus.

The figures in the column headed "relative humidity" show the proportion of moisture held in the air relative to the amount which could be retained at the temperature indicated by the dry-bulb thermometer, *saturation being 100 in all cases.*

Record of temperature and relative humidity of the

DATE.	Temperature of Outer Air.		No. 1, Hot-Air Furnace.				No. 2, Hot-Air Furnace.				No. 3, Hot-Water and Steam Pipes.			
			9 A.M.		2 P.M.		9 A.M.		2 P.M.		9 A.M.		2 P.M.	
	9 A.M.	2 P.M.	Temp.	Humidity.	Temp.	Humidity.	Temp.	Humidity.	Temp.	Humidity.	Temp.	Humidity.	Temp.	Humidity.
1868														
Jan. 27	17	24	65	47	64	51								
" 28	21	25	64	49	65	51					65½	40	70	40
" 29	25	30	62	50	66½	55	68½	49	63½	49	69	40	69½	40
" 30	26	25	62	59	67	52	65½	51	65½	48	70	40	73	37
" 31	14	26	57	53	69	50	68	44	67½	43	68	38	72	39
Feb. 1	17	25	59	50	65	49	64	47	69	45	66	40	70	38
" 2	21	32	64	47	66	52	65	47	66½	51				
" 3	5	8	62	50	66	52	69	45	65	47	61	39	64	40
" 4	14	25	57	53	66	50	57	47	66½	43	64	37	69	36
" 5	9	27	63	47	66	50	68	42			78	33	75	37
" 6	27	32	64½	53	68	53	73	39			79	41	74	45
" 7	18	20	65	52	64	50	69	42	65	44	73	45	68	44
" 8	—2	18	58	44	63	50	64½	42	64	45	72	45		
" 9	32	40	63	50	67	55	64	44	69½	47				
" 10	16	16	63	50	68	50	70	47	73	41	64	56	76	41
" 11	11	21	60	50	65	52	65½	43	64	45	70	45	74	45
" 12	12	26	60	50	65	52	68½	43	72	41	67	42		
" 13	29	37	62	50	65	52	69	45	70	35	68	44	72	45
" 14	15	17	66	49	66½	48	69½	45	71	42	68	42	76	43
" 15	28	39	63	50	63	56	65	49	61	53	68	44	72	45
Mean temp.	17.7	25.6	62		65.7		66 8		67.1		68 8		71.6	
Mean hum'y.				50.1		51.5		45.1		44.9		41.8		41

air of houses warmed in several different ways.

No. 4, Hot-water Pipes.				No 5, Grate burning Anthracite.				No. 6, Steam Pipes.				No. 7, Furnace burning wood.			
9 A.M.		2 P.M.		9 A.M.		2 P.M.		9 A.M.		2 P.M.		9 A.M.		2 P.M.	
Temp.	Humidity.	Temp.	Humidity.	Temp.	Humidity.	Temp.	Humidity.	Temp.	Humidity.	Temp.	Humidity.	Temp.	Humidity.	Temp.	Humidity.
								65	49	65	49	61	50	66	47
		71	38					65	49	65	49	64	47	59	56
64	42	72	43	65	53	71	47	65	47	65	47	66	47	63	50
69	40	73	43	65½	48	71	47	64	47	64	47	69	42	65	47
67	40	72	43	61	53	70	49	58	50	59	50	63	44	59	50
69	38	74	38	65	49	69	50	65	47	65	47	65	44	62	47
				65½	51	68	47	66	44	68	44	67	42	67	47
				64½	44	70	49	62	44	62	44	60	44	64	42
64	37	71	38	62	49	69	46	61	44	62	44	61	44	63	44
67	40	75	37	64	47	70½	48	62	44	64	47	59	47	68	40
68	40	72	45	65½	51	70	49	67	47	70	44	68	44	70	42
64	42	72	43	64½	53	71	48	60	47	64	47	69	38	62	44
64	37	72	40	64½	50	66	50	62	44	63	44	62	42	63	42
				69	47	70	51	65	49	66	50	69	42	68	47
61	44	67	40	67	49	70	49	66	47	68	42	67	44	72	41
68	36	71	38	63½	48	69½	48	66	42	66	44	61	42	68	40
64	39	71	40	69	47	69	47	64	42	70	42	67	42	62	50
68	40	66	47	67	50	71	52	64	44	64	47	68	50	69	50
67	40	66	47	67½	47	69	51	65	44	64	42	64	47	68	42
65	42	69	40	66	47	70	49	65	44	68	44	70	47	65	49
65.9	39.8	70.9	41.2	63.1	49	69.7	48.7	63.8	45.7	65.1	45.7	65	44.4	65.1	45.8

It will be seen by the preceding table that the greatest relative humidity, or the moistest air, was found in the house warmed by air which had passed over iron heated to a very high degree, — certainly often during this period to 1,000° Fahrenheit.

The least relative humidity, the driest air, was found in the library of the Athenæum, in which it had passed over pipes heated to a point always less than the boiling-point of water, and usually about 170° Fahrenheit.

The library of the State House (hot-water and steam pipes) was almost equally dry.

Both the libraries were drier than either of the dwelling-houses, and probably for two reasons. The temperature was higher, and the relative humidity diminishes rapidly above a temperature of 65°. Also the absence of cooking operations and of collections of water such as are found in all dwelling-houses contributed no doubt to the result.

No. 5, the room warmed by an open grate burning anthracite, is above the average as regards moisture, but it may have been and probably was affected by the evaporation of water in the furnace.

Of the four remaining dwelling-houses, the differences of humidity are only such as might be expected from their comparative size and from the different number of persons occupying them. No. 1 probably received more vapor from respiration and from culinary operations than either of the others.

Nos. 2, 6, and 7, one warmed by a common anthracite furnace, another by steam pipes, and the third by a wood furnace which was often heated in parts to the point of incipient redness, show almost precisely the same results.

We think the conclusion may fairly be drawn from this record that *iron heated to any point possible in our furnaces has no power to abstract moisture from the air.* Theory and practice in this respect are in perfect accord. Each confirms the other.

In so far as artificial evaporation is concerned it is *equally* needed with steam pipes * and hot-water pipes as with fire-pots heated red-hot. If the air of a room warmed to 65° or 68° by hot-water pipes is pleasant, and the air of a room warmed to 65° or 68° by an anthracite fire is unpleasant, in both cases no artificial evaporation being employed, the difference is not in the simple dryness of the air and must be in something else.

Moreover if the anthracite-heated room is really made more tolerable at these temperatures by the addition of vapor, as many intelligent persons maintain, it appears to the writer that it must be through some action of vapor as yet unexplained. Certainly the *need* of additional vapor is not felt at these temperatures with radiating open fires of wood or bituminous coal, or with heat derived from hot-water pipes or steam pipes.

* Buildings specially arranged for drying cotton cloth, wood, or other materials, are usually heated by steam pipes.

The degree of relative humidity which air should possess for healthy respiration has been the subject of much inquiry, and particularly in our anthracite-burning community where it is no uncommon thing to find the temperature of a room 75° or 80° at a height of five feet from the floor, and ten degrees higher at the ceiling. We believe that a right understanding of this most important subject has not yet been reached, and that some of the difficulties in the solution of the question are to be found in the unfitness of air for respiration from other causes than its condition of humidity. Some of these causes we shall presently refer to. The quality of air in the library of the Boston Athenæum is worthy of the notice and observation of those who are interested in the subject. This air, coming through coils of iron pipes containing water much below the boiling-point, it will be seen by the preceding table is exceedingly dry and yet perfectly agreeable, and its wholesome character when as is usually the case it is frequently changed by ventilation can hardly be doubted. One reason why the need of special evaporating apparatus in our houses is so much insisted on is a purely theoretical one. The argument is something like this: Air taken from out of doors at the average winter temperature of 28° with a relative humidity of 60 (saturation being 100) contains 1.26 grains of vapor to the cubic foot.

Raise the temperature by a furnace so that the

thermometer shall be at 68° within the house, and unless water is artificially added the relative humidity will be 17, which is drier than the air of a desert. All this is strictly true, yet practically in our houses it is not so. Water *is* added in all such cases, but the sources of its supply are not obvious. They are found in respiration, in all the numerous collections of water about the interior of houses, in culinary operations, in the stores of water contained in all hygroscopic substances (and almost everything is hygroscopic), and very possibly by the absorption of additional amounts of vapor from the outer air through all the channels concerned in natural ventilation, by windows and doors, and cracks and crannies of every kind. There is however in spite of all these means of adding to the relative humidity of heated air a certain obscurity as to the sources of supply. Thus it is stated by Haller* that experiments carried on over six years with the Meissner stove common in Germany showed that the relative humidity was not lessened at all by moderate warming.

The preceding table gives abundant proof that the relative humidity of air raised 50° or 60° is not changed in anything like the proportion which would exist theoretically, and which would certainly exist practically if all sources of additional moisture could be excluded.

* Die Lüftung und Erwärmung der Kinderstube und des Kranken Zimmers, Von D. C. Haller, 1860.

Another cause of error in reasonings upon this subject seems to be found in overlooking the power of adaptation which man possesses to changed conditions of humidity, as well as to so many other of the circumstances by which he is surrounded. The human body cannot be regarded as an inanimate hygroscopic substance liable to warp and crack like a piece of furniture. A close analogy may be discovered between the capacity not only to bear, but to enjoy the highest health under extreme alternations of both temperature and humidity. Animal heat is maintained at about 98° whether the temperature of the air is 20° below zero or 100° above. It by no means follows because the air is dry that the evaporation from the human body is in proportion to its aridity, although this no doubt has an effect. But supposing this excessive evaporation were proved, it still remains to be shown that the effects upon health are injurious. A man is in himself a reservoir of water, three-quarters of his whole bulk being composed of that element, and he is also a great evaporator, giving off by the skin and lungs, according to the best authorities, from 25 to 40 ounces or about a quart of water per day. This exhalation is doubtless controlled, limited, and regulated by the nervous system. Certainly knowing these facts we may at least doubt the expediency of adding the evaporation of water to the heating apparatus in any crowded assembly.

A theatre or lecture-room containing 2,400 people is already provided with an evaporating apparatus throwing into the air 25 gallons of water per hour, and under such circumstances the air soon becomes saturated unless frequently renewed. That saturated warm air is exceedingly oppressive is a fact which everybody recognizes in the dog-days of August. Those who have been long exposed to the summer air of the low-lying wet regions of our southern coast will not need to be reminded of it. On the other hand, the dry air of the interior of the South American continent is reported by Boussingault and others to be exceedingly healthful and agreeable. Who can say that the dry air of Minnesota is less salubrious than the moist air of Nantucket or Newport? There is no reason to suppose that either is wanting in conditions of humidity favorable to health and long life. The meteorological tables of the Smithsonian Institution enable us to compare these two regions for 1859. New Bedford, Mass., at 90 feet elevation above the sea, has a mean relative humidity of 80, while Fairfield, Iowa, 940 feet elevation above the sea, has a mean relative humidity of 61, saturation being 100. In the three winter months, the minimum humidity was often observed at Fairfield as low as 10, and sometimes even 5. The same is no doubt true of St. Paul, Minnesota, so much resorted to by invalids; but of the hygrometry of Minnesota

we can learn nothing positive from any reports published by the Smithsonian Institution, although it is understood that they have a mass of observations made since 1859 but not yet reduced to a form for publication.

Evidence of the healthfulness of dry air is also afforded by the experience of arctic voyagers. In those excessively cold regions the air of the cabins of vessels, heated to 60° or 70°, must be as dry as anything which can be found in the world. It is stated by Mr. Steinmetz, an English writer on meteorology, that the wainscoting of the cabin of a ship in the arctic regions sometimes shrinks half an inch in a panel of fifteen inches width. Yet it is well known that the health of crews in the frozen seas is singularly preserved.

In view of this tolerance of air almost devoid of vapor and the ready adaptation of the human system to such extremes, it may be suspected that it would be more reasonable to regard the absolute as well as the relative humidity of air. Although as before stated air raised from 28° to 68° becomes *relatively* dry, it remains *absolutely* nearly as humid as before; the only difference being in its expansion of volume, which between the points referred to would be only about nine-hundredths of one per cent. It may also be imagined that the human body becomes in the winter months attuned (if the expression may be allowed) to a diminished amount of aerial

vapor, and that a single grain to the cubic foot, which is even more than we get in the outer air with the temperature at zero, is in accordance with some general plan of nature whose workings in this respect as in so many others are imperfectly understood.

The tolerance by man of air possessing the extremes of humidity is shown on the one hand by the good health of sailors in tropical seas breathing air very nearly or quite saturated with moisture, 10.8 grain to the cubic foot at 80° Fahrenheit; and on the other hand by the robust and vigorous health enjoyed by lumbermen and arctic adventurers breathing air which, at 10° Fahrenheit, holds but 1.1 grain to the cubic foot. In the latter case we may also suppose that the air is raised in temperature even higher than the tropical air before it reaches the air-cells of the lungs, and supplied with at least ten or twelve grains of vapor to the cubic foot before it is expired.

Yet this hydrating process is performed for an indefinite period without the least inconvenience, if the man is duly supplied with clothing and food.

One of the most marked disadvantages on the score of health attending a very moist artificial atmosphere is the tendency which is observed in the vapor to combine with organic impurities. This fact has been frequently noticed, and is specially

referred to by Dr. Parkes, of the Netley School, in his invaluable treatise on Hygiene.* He says: "The most important class of diseases produced by impurities in the atmosphere are certainly caused by the presence of organic matters floating in the air; and from the way in which, in many cases, the organic matter is absorbed by hygroscopic substances, it would appear that it is often combined with, or is at any rate condensed with, the water of the atmosphere."

Having thus entered a general protest against a very humid artificial atmosphere, and stated our belief, and the reasons on which it is founded, that a dry quality of air has many advantages, and if free from impurity is perfectly consistent with health, it remains to be said that common experience shows that a room heated to 70° and upwards at a height of five feet from the floor, becomes more tolerable by the artificial addition of moisture unless it is receiving vapor from the presence of a large number of persons or from many gas-burners or other modes of lighting. Where the register is in the floor and the heated air ascends vertically, a thermometer in a room will show the temperature to be very much higher near the ceiling. With this degree of heat there can be little doubt that evaporation from the skin and lungs is really increased, and this in equal degree whatever may be the

* Parkes' Hygiene, p. 91.

mode of heating. Could heat be more equally diffused throughout a room warmed by a register as it is by the radiant heat of an open fire, such temperatures as we now so often encounter in dwelling-houses would not be demanded, and the need of artificial evaporation would not be felt; but in point of fact it is very common to find the carpet warmed only to about 60°, while at the height of the head it is 70°, and at the ceiling many degrees higher. Artificial evaporation also tends to reduce the temperature, a certain amount of heat being abstracted by the conversion of water into vapor.

There are many persons so constituted that a moist air is more agreeable to their feelings than a dry air, and for the same reasons doubtless, whatever they may be, which would lead them to prefer the climate of Nantucket to that of the interior of the continent.

It should also be stated that in certain inflammatory and irritable conditions of the respiratory organs a warm moist air is of inestimable benefit. Having thus said more than we intended on the subject of air moisture, it only remains to add that the evaporating apparatus usually placed in furnaces is quite inadequate to produce any effect appreciable by the wet-bulb hygrometer. To change the humidity of the air under good ventilation, a large and shallow pan exposed to the full heat of the furnace and constantly supplied by a cock whose movements are

regulated by a ball floating on the water, or else a renewal of the water by pailfuls daily, are indispensable.

Probably the most useful way in which to add vapor to the air of a dwelling-house is by some attachments over the registers, provided they do not obstruct the ingress of air on which both warming and ventilation are dependent. By such adjustments moist air may be thrown where desired, and the inconvenience and discomfort of finding it condensing and dripping from the cold glass of the skylight may be in part at least avoided.

If as we believe the peculiar effects upon the human system attending the combustion of anthracite are not due to any change in the character of air or its contents by the contact of highly heated iron, or to the abstraction of moisture, we must look next at the composition of this fuel and the products of its combustion.

Anthracite coal is nearly pure carbon. Ure's Dictionary and Professor Bloxam give the analysis of American anthracite as follows: —

Carbon,	92.30	Carbon,	90.39
Volatile Matters,	6.42	Hydrogen,	3.28
Ash,*	1.28	Nitrogen,	0.83
		Oxygen,	2.98
	100.00	Sulphur,	0.91
		Ash,*	1.61
			100.00

* Chiefly silica, alumina, and peroxide of iron.

The composition of anthracite may be said to differ from that of all other fuel in common use, except charcoal, in the very large proportion of pure carbon and the very small proportion of compounds of hydrogen.

The products of its combustion may be stated to be carbonic acid and carbonic oxide gases, with a small amount of sulphurous acid gas and watery vapor.

Anthracite burns without smoke or soot and almost entirely without flame. When combustion is complete the products may be said to be carbonic acid gas and water, and the fumes of sulphur which although small in amount are often perceived.

Combustion is however seldom complete except in the furnace of a steam-boiler where the heat is intense and small supplies of fresh fuel are constantly added; and not even in this case unless the supply of air passing through and over the fire is abundant. Every one has observed the difficulty in bringing a mass of anthracite in a stove or grate to the point of free and complete ignition, particularly in cold weather. Owing to the great density of the fuel heat is conducted away from the surface, and such exposed portions can hardly be raised to the temperature required for burning.

We will suppose the fire to be fairly kindled and a mass of anthracite thrown over it. The process which follows may be thus described. The actual

combustion of the lower range of coal in contact with the fire gives origin to carbonic acid gas. This, rising through the mass of heated coal above, is deprived of a portion of its oxygen and issues from the surface as carbonic oxide gas. In this form it escapes by the flue for a period depending on the activity of the fire and the amount of air admitted. Finally, when the temperature of the mass is raised, if the supply of air is sufficient it breaks into a pale-blue flame signifying its reconversion into carbonic acid gas. This may often be observed on suddenly opening the door of a stove or furnace. Without a supply of air it continues to pass off as carbonic oxide; with a supply of air and a sufficiently elevated temperature it burns and becomes carbonic acid.* Sulphurous acid gas from the combustion of the sulphur is continually given off in small amounts.

The properties of these gases are now to be considered. The opinions which have for a long time prevailed concerning the poisonous nature of carbonic acid are greatly modified by recent observations.

Its singular harmlessness and even its refreshing

*Barreswill (Journal für Praktische Chemie, vol. LXII.) thinks that at low temperatures, carbon is converted into carbonic acid, and at high temperatures into carbonic oxide; and explains in this way the more poisonous influence of a defective flue than of a pan of open coals.

qualities when received by the stomach in effervescing drinks; the impunity with which considerable amounts can be breathed by the workmen in soda-water factories; its use by Dr. Simpson of Edinburg as an anæsthetic agent, diluted with two parts of air, — these and similar observations have led many chemists to doubt whether it was by itself, strictly speaking, poisonous. The statements made by physiologists and chemists are still conflicting, but the tendency of opinion is evidently to rank it rather with the obstructors of respiration than with the poisons.

Dr. Taylor says, in reference to this question, "It is absolutely necessary to make a distinction between the contamination of air by the addition of a proportion of free carbonic acid, and the case where this gas is produced by combustion or respiration." *

M. Bernard states that carbonic acid is not poisonous, and that when an animal dies from breathing this gas its death is owing to the mere want of respirable air; hence he considers its action to be purely negative like that of nitrogen; in short that it operates not by poisoning but by inducing suffocation. †

M. Guerard has breathed large amounts of carbonic acid from the expansion of liquefied acid without inconvenience. His opinion is that "car-

* Taylor's Med. Jurisp., p. 711.

† Substances Toxiques, p. 137.

bonic acid is rendered more fatal by the presence of carbonic oxide, and that a quantity of each, which if respired alone would be innocuous, may become fatal to life if respired in mixture." *

Regnault † asserts that carbonic acid can be breathed with impunity provided there is sufficient oxygen to maintain respiration. We shall again refer to the action of this gas when mingled with others, but meanwhile it may be said that it seems most probable that it does really possess active noxious properties of its own and that when respired its effect is narcotic. There is an important distinction certainly to be made between carbonic acid and nitrogen, since the former is readily absorbed by the blood. At the same time its most injurious influence is doubtless found in the obstacle which its presence offers to the free escape of carbonic acid by diffusion from the blood of the venous circulation in the lungs.

Concerning the properties of carbonic oxide gas, there is no discrepancy of opinion among physiologists or chemists. It is an active poison, *inodorous*, tasteless, and absorbed by water only in a slight degree.

Leblanc says: "One volume of it diffused through one hundred volumes of air totally unfits it to sustain life; and it appears that the lamentable

* Annales de Hygiene, 1843, T. 2, p. 55.

† Taylor's Med. Jurisp., p. 716.

accidents which too frequently occur from burning charcoal or coke in braziers or chafing-dishes in close rooms result from the effects of the small quantity of carbonic oxide which is produced and which escapes combustion, since the amount of carbonic acid thus diffused through the air is not sufficient in many cases to account for the fatal result."*

Leblanc analyzed the vapor from burning charcoal which proved fatal to a dog, and found carbonic acid 4.61 parts, carbonic oxide 0.54 parts.

Watts' Dictionary of Chemical Science says: "Carbonic oxide gas is very poisonous, acting chiefly on the nervous system, causing giddiness, sometimes acute pain in various parts, and asphyxia."

A very complete examination of the poisonous properties of carbonic oxide has been made by M. Bernard, Professor in the College de France.† He says: "Carbonic oxide is one of the most poisonous gases known. For a long time it was supposed that under these circumstances (death by the fumes of charcoal) the poisonous agent was carbonic acid, which in all combustion is produced in considerable quantity. Recently in examining the subject with more care it has been discovered that besides carbonic acid, there is formed in these cases another very deleterious gas, — carbonic oxide.

* Bloxam's Chemistry, and Taylor's Med. Jurisp.

† Leçons sur les effets des substances toxiques.

Carbonic acid was then considered quite innocent by most of those who admitted that in poisoning by the fumes of charcoal the deadly agent was carbonic oxide. We have seen that this is incorrect, and that death may be caused by either of these gases. In the case of carbonic oxide, death results from poison; in the case of carbonic acid, from asphyxia."

Many experiments were made by M. Bernard before his class showing the effects of carbonic oxide on the lower animals. The results are seen in the action of this gas upon the blood, by which it is readily taken up through the lungs and passes into the general circulation. He finds the globules of the blood to be paralyzed, in a certain sense, by its presence; that they become unfitted for their office; that the blood remains red; that the conversion of arterial into venous blood is arrested; and that the animal dies as if by prussic acid. When the amount of this gas administered is insufficient to cause death the animal recovers on being supplied with atmospheric air and exhibits no subsequent ill effects.

M. Bernard also confirms the opinion of M. Guerard, before referred to, that the mixture of carbonic acid and carbonic oxide is more dangerous than either respired alone.

Dr. Letheby, Professor of Chemistry in the Medical College of the London Hospital, says, "he has tried the effect of carbonic oxide on birds and young

Guinea pigs. An atmosphere having two per cent. of this gas will render a Guinea pig insensible in two minutes, and in all these cases the effects are the same; they fall insensible, and either die at once with a slight flutter hardly amounting to convulsion, or they gradually sleep away as if in profound coma. The post-mortem appearances are not very striking; the blood is a little redder than usual, the auricles are somewhat gorged with blood, and the brain is a little congested." * He also says that "This gas in a more diluted condition is still able to exert an injurious action, and it is very probable that the singular catastrophe which happened at Clayton Moor, in 1857, was caused by the diffusion into the air of carbonic oxide gas from the neighboring furnaces. There is a row of cottages near to these furnaces, where, in the month of June, 1857, a number of persons were seized with insensibility which soon passed in some cases into coma and death. About thirty persons were thus attacked, and six died. The effects were attributed at the time to the escape of sulphuretted hydrogen from the slag on which the cottages were built; but it is more than probable they were caused by the oxide of carbon from the furnaces."

M. Adrien Chenot, a chemist of the French Academy,† relates a case of poisoning by this gas in his

* Chemical News, April, 1862.

† Comptes Rendus, T. 38, 1854.

own person. Being anxious to examine the gas yielded by his process of smelting zinc ores, and not having a suitable instrument at hand, he drew a mouthful of carbonic oxide from his furnace by a pipette. While thus holding it he was suddenly struck on the back by an assistant and the gas was inhaled. He fell as if struck by lightning; the eyes were turned back in their orbits, the skin was discolored, the veins were swollen and presented a black tint under the skin, and there were violent pains in the chest. After removal to the open air sensibility gradually returned. Among the effects described, M. Chenot says he felt as if his brain was violently compressed; for several days there was a feeling of depression and languor, difficult digestion, and obstinate and heavy sleep; and for many subsequent weeks a morbidly excited state of the nervous system.

Similar effects are described in the same volume of the "Comptes Rendus" as resulting from the escape of carbonic oxide from a balloon which had been filled by the gas (water gas) produced by the passage of vapor over charcoal heated to redness. The aeronaut nearly lost his life.

M. Chenot also relates several instances in which poisoning resulted from inhaling carbonic oxide when greatly diluted.

The deadly gas thus described is produced abundantly in all ordinary combustion of anthracite.

Its pale blue flame presents an appearance peculiar, distinctive, and not to be confounded with any other. It flickers over our grates, stoves, furnaces, and appears in whatever form anthracite is burned. It is seen at night burning as it issues from the chimneys of factories and steamboats using this fuel. Even the free combustion in such places where supplies of coal are added every few minutes is seen to be insufficient to burn and convert it into the comparatively safe carbonic acid until it reaches the outer air.

Does this gas really escape from our grates, and stoves, and furnaces, and mingle with the air we breathe? Although carbonic oxide is completely inodorous, another gas with which it is mixed is not. If one escapes it may fairly be presumed the other does also. Who of us is not perfectly familiar with the pungent, irritating fumes of sulphurous acid gas, which we are liable to meet with wherever and in whatever form hard coal is burned, whether in open grates, stoves, or furnaces? Perceptible in various degrees, its existence is often denied by those who have been long accustomed to it; for habit dulls the sense of smell in a remarkable degree; but coming from the open air it is often evident enough. Persons subject to spasmodic asthma can perceive it through its effect upon the air-passages. When the draft of a furnace is checked by the sudden cooling of the flues from the addition of fresh coal it is

especially evident. In an open grate with a good draft it is least perceptible; but even here when the grate is newly filled it can generally be perceived by putting the face close to the mantel-shelf.

The presence in anthracite of this minute proportion of sulphur is of real advantage in its domestic use, since like the irritating smoke from wood and soft coal it warns us of danger and furnishes a measure, however imperfect, of the amount of poisonous and inodorous material with which it is associated. Without it the combustion of anthracite for warming our houses would be far less safe than it actually is.

The proof that it escapes into the air-chamber of furnaces is not however dependent upon the sense of smell. Litmus paper placed over the register of an ordinary furnace in which no smell of sulphur may be perceived is in a short time not only reddened but bleached, showing unmistakably the presence of sulphurous acid.

Another kind of proof that carbonic oxide gas mingles with the air of our houses is found in its observed effects; and in this respect it resembles the evidence on which certain green papers have been convicted of conveying arsenic poison to the air of rooms. Arsenic found in the paper, and a certain train of symptoms corresponding with known effects of arsenic in the bodies of those who breathe the air which has been in contact with the paper. An ino-

dorous, insidious, stupefying, poisonous gas in the grate or furnace, and in the persons of those exposed to its influence peculiar sensations, vaguely associated by experience with the burning of hard coal, but having a remarkable correspondence with the ascertained effects of the inhalation of carbonic oxide. Chemists are not required to find the arsenic in the air to prove the reality of the poison, neither have they yet discovered the carbonic oxide. Its discovery in either case when existing in amounts only sufficient to produce the effects observed would be a matter of great difficulty.

It may however be objected that the air of the room is directly exposed to arsenic poison, while the poison of carbonic oxide is safely conducted up the flues and out of the house. That it is so conveyed for the most part is certainly true, or we should none of us be living to consider the question; but that a portion is also thrown into our houses may be shown by other reasons than those derived from its observed effects or from its association with the fumes of sulphur.

An open grate burning soft coal throws into the room particles of soot as all house-keepers know by its effect upon furniture.

An open fire of wood communicates to the room a peculiar flavor of acetic acid and often a trace of pungent smoke.

In both cases the amount of these matters is de-

termined by the completeness of the draft, the state of the weather, the way in which the fire is built, the opening and shutting of doors, and a variety of similar conditions familiar to everybody. There is no reason why the poisonous gases from anthracite burned in a grate, although invisible, should not escape with equal freedom and from the same causes. There is even more reason to expect it since modern flues for using this coal are frequently made only eight inches in diameter. This size of flue stands in no proper relation with the air-space exposed in front of the fire; and consequently a considerable amount of air being drawn within the range of such a fire and receiving a portion of the products of combustion, fails to find egress and flows in part over the mantel-shelf.

Cast-iron stoves and furnaces are necessarily made in pieces, and these pieces must separate with the expansion and contraction of the metal.

No fastenings can resist this power, and some of the makers of furnaces recognize the fact by making the pieces to simply rest upon each other in grooves filled with sand or with some other material not firmly fixed to the iron. As these parts are subjected by the application of heat to continual change of form, some portions being also exposed to greater heat than others, they are warped, the fittings become loose, and openings are left through which the products of combustion leak into the air-cham-

ber. How many furnaces, new or old, would prove to be water-tight in the fittings of their parts, supposing them to be put to such a test?

Yet in the way furnaces are often used to save coal and superfluous heat, the dampers partly closed, or, which is the same thing, air admitted to the funnel between the fire and the flue, a very slow and imperfect combustion going on, and the gases within the fire-pot nearly stagnant, nothing short of water and air-tight fittings can prevent an escape from taking place between the joints.

Cast iron is also frequently defective in its structure, and this is so well recognized a fact that the most rigid tests are required before it can be used for many of the purposes to which it is applied. Cast-iron tubes for the conveyance of illuminating gas are subjected to very heavy pressure before they can be safely used by the gas companies. It is quite as important that our anthracite-burning stoves and furnaces should be examined for the discovery of imperfections with equal care; but that they are so in all cases may at least be doubted.

Certainly, wherever and however an opening exists, whether by imperfect fittings of the parts or by defects in the casting of the iron, the law of diffusion of gases must operate to mingle the contents of the fire-pot, furnace, and smoke-pipe with the external air unless the current passing up the flue is very active.

But it is not even essential to prove that iron stoves and furnaces permit the passage of gases through their joints and fittings or through defects in their casting. A surprising discovery has quite recently been made in France which has a most important practical bearing upon the question we are considering. MM. St. Claire Deville and Troost, of the French Academy, have published in the "Comptes Rendus" an account of their experiments upon the permeation of metals by gases, from which it appears that several metals, including iron, when heated to a dull red heat, permit the passage of gases directly through their substance, and this by virtue of a property thus described: "In metals the porosity results from the dilatation which heat induces in the intermolecular spaces. It is related to the form of the molecules, which we may suppose to be regular, and with their '*alignement*,' which determines the cleavage or the planes of fracture among crystallized masses." *

It will be observed that this theory of the phenomenon harmonizes perfectly with the new philosophy of heat as explained by Professor Tyndall, in his "Heat a Mode of Motion." Of the fact of the penetration of metals by gases, abundant evidence is presented.

The first of the articles by MM. St. Claire

T 57 p. 102, 1864

* Comptes Rendus, T. 57, p. 965, 1863.

Deville and Troost is entitled, "Upon the permeability of iron at high temperatures."* It is here shown that heated cast iron permits the passage of hydrogen gas; the tubes through the walls of which it freely passed were of the thickness of from three to four millimetres, or about one-seventh of an English inch. The second communication on the same subject is entitled, "On the passage of gases through solid homogeneous bodies."† The following is an extract: "I am able to demonstrate to physicists the great interest which attaches to these experiments upon substances as perfect as iron and platinum. These bodies resist elevated temperatures; their feeble conductibility facilitates very much the construction of apparatus; they are not permeable at ordinary temperatures, but this property develops as they are heated. As these substances are homogeneous the phenomena which they exhibit are free from disturbing causes such as attach to experiments upon materials obviously porous."

In seven experiments which are minutely described hydrogen, nitrogen, and *carbonic oxide* gases passed readily through the walls of cast-iron tubes three millimetres (about one-tenth of an English inch) in thickness.

The experiments of the French chemists are confirmed in all essential points in England by

* Comptes Rendus, T. 57, 1863. † Comptes Rendus, T. 59, 1864.

Prof. Graham, F. R. S., Master of the Mint. Our immediate and practical concern is with the penetration of iron by carbonic oxide and carbonic acid gases. It appears that it is by reason of this property that iron is converted into steel.

The comments of Prof. Graham upon this penetration of iron by carbonic oxide are as follows:—"Pure iron is then capable of taking up at a low red heat and holding when cold, 4.15 volumes of carbonic oxide gas. This fact, confirmed in various experiments, explains partly, if not entirely, the abundance of carbonic oxide observed among the natural gases of iron in several experiments of MM. Deville and Troost. In the course of its preparation wrought iron may be supposed to occlude six or eight times its volume of carbonic oxide gas which is carried about ever after. How the qualities of iron are affected by the presence of such a substance, no way metallic in its characters, locked up in so strange a way but capable of reappearing under the influence of heat at any time with the elastic tension of a gas, is a subject which metallurgists may find worthy of investigation. The relations of the metal iron to carbonic oxide gas appear to be altogether peculiar. They cannot fail to have a bearing upon the important process of *acieration*. . . . .

"The inquiry suggests itself whether acieration would not be promoted by alternation of tempera-

ture frequently repeated. The lowest red heat, or a temperature even lower, appears to be most favorable to the absorption of carbonic oxide by iron, or for impregnating the metal with that gas; while a much higher temperature appears to be required to enable the metal to decompose carbonic oxide, to appropriate the carbon and become steel." *

It clearly appears from the experiments of MM. Deville and Troost, and the remarks of Prof. Graham, that iron at a low red heat, or even lower, can take up this most deadly poison from our anthracite coal and permit its passage directly through the substance of the metal.

Does this not offer a reasonable explanation of the injurious influences of our iron stoves, furnaces, and smoke-pipes, when excessively heated?

These influences are real. It cannot be mere imagination which has so generally associated highly heated iron with unpleasant and peculiar sensations; yet the connection has been mysterious. To say that air is scorched is vague and indefinite. The component parts of air are certainly unchanged; the oxygen, nitrogen, and watery vapor remain as before. The dust in the air is, or may be, charred or even burned; but is it at all probable that the charring or the complete combustion of minute amounts, hardly perceptible by the sense of smell, of the substances of which dust is composed, even

* London Philosophical Magazine, Vol. XXXII., 1866.

if it took place in the still air of an unventilated room, could give rise to a *peculiar form of headache, to languor, oppression of respiration, and general disturbance of nervous functions?*

? p 30-33 We have seen that there *is* an agent capable of producing these effects; that carbonic oxide always produces them when inhaled; that carbonic oxide is formed in all combustion of anthracite; that it is liable to escape in several ways from the grates, stoves, and furnaces in which it is burned; and that as these latter are commonly used it can hardly fail to escape in greater or less amounts; and that sulphurous acid, an irritating gas and readily recognized, is known to escape.

We therefore feel justified in expressing our conviction that the inhalation of small amounts of this active blood-poison, *carbonic oxide gas* (mingled no doubt with carbonic acid gas, and its poisonous quality thus increased), is the chief and probably the only cause of the unpleasant sensations and the injurious influences so commonly associated with the combustion of anthracite coal.

The first step in the prevention of disease is the discovery of its exciting cause; the next step is its removal. The reasonable question will be asked: "If these things are so, what is the remedy?" To give up the use of anthracite coal as a means of warming houses would seem to be impossible. The next best thing is to provide for the free escape by

the smoke-flue of these poisonous gases. To do this we should

1st. Never allow our iron fire-pots to attain that degree of heat which permits the passage of gases through their substance.

2d. We should have perfect castings, and as few joints as possible in our stoves and furnaces, and these should be horizontal, and never vertical joints.

3d. We should never check the free ingress of fresh air, and the perfectly free egress of the products of combustion by dampers, valves, or similar contrivances of any sort.

4th. We should so burn the coal that under all possible circumstances a pressure of air from without inwards may be exerted upon the fire-pot, furnace, and smoke-pipes.

That this manner of using coal will be found expensive is unquestionable; that keeping a free burning fire in all weather will be found uncomfortable, is equally true. Perhaps in the progress of science some means may be found to obviate these and other difficulties.

The best and safest modes of warming houses now practised are undoubtedly those in which air, drawn from without, is passed through coils of pipes filled with either steam or hot water in an enclosed space in the cellar, and thence distributed above. They are however very expensive in their first cost, not easily regulated, and liable to freeze and require

repairs when most needed in our coldest weather if the fier is neglected.

Furnaces for burning wood have also many advantages. They are simple in construction, and give an abundance of heat of the most agreeable quality. The expense of fuel, even in Boston, is very little more than that of coal. The disadvantages are, first, the need of abundant cellar or yard-room for the storage of wood; second, the addition of fresh fuel four or five times a day; third, the need of large old-fashioned flues to carry off the smoke, a modern-sized flue requiring frequent cleaning; and, fourth, the condensation of the products of the distillation of wood, impure acetic acid, in and about the flue and chimney. With a large flue in a house in the country, where wood can be bought cheap, and with plenty of room to store it, the wood-burning furnace would be preferable to any other.

We can see no reason why illuminating gas may not some day be made cheap enough to furnish heat as well as light to our homes. It is possible certainly to imagine that an arrangement of Bunsen burners, easily regulated and graduated according to the weather, and furnishing as products of combustion only carbonic acid and vapor to be conducted into a flue as soon as formed, might be made to supply any amount of heat required for domestic purposes.